Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Computer Science 8 (2012) 69 – 74

Procedia
Computer Science

New Challenges in Systems Engineering and Architecting
Conference on Systems Engineering Research (CSER)
2012 – St. Louis, MO
Cihan H. Dagli, Editor in Chief
Organized by Missouri University of Science and Technology

Applying Systems Engineering on Energy Challenges

Jamal Safi[a], Gerrit Muller[a]*, and G. Maarten Bonnema[b]

[a]*Buskerud University College, P.O. Box 51,3 3603 NO Kongsberg, Norway*
[b]*University of Twente, P.O.Box 217, Enschede, NL-7500AE, The Netherlands*

Abstract

Systems engineering is a discipline with methods and techniques to address complex problems. We want to study how Systems Engineering methods can help to address today's grand challenges, such as the energy problem. The first step is problem definition which aims at articulating the problem in its context as clearly as possible.
Humanity will have to cope with the energy problem, one of the most critical challenges of humanity in this century. The energy problem itself is related to other challenges facing humanity like water, food and poverty. The key challenges concerning energy are climate change and other environmental impact of energy production and use, energy security, and long-term sustainable and affordable access to energy.
The intention is to investigate the energy problem through applying system engineering practices aiming to reach a more clear, concise, and consistent understanding of the energy problem. This will help in both reaching a common understanding platform for all those involved in the energy problem and pave the way to identify the needs and thus suggesting and assessing solutions. Our first attempts to formulate a problem statement and to identify energy needs indicate that there are many assumptions in current literature.

Keywords: systems engineering; modeling; energy

1. Introduction

Energy is the fuel for growth, an essential prerequisite for economic and social development. By 2050, energy demand could double or triple as population rises and developing countries expand their economies and overcome poverty. Transitions in our energy infrastructure will be needed to facilitate moving towards more sustainable development with minimum effects on the environment. However, as

* Gerrit Muller. Tel.: +47 32869594; fax: +47 32869551.
E-mail address: Gerrit.muller@hibu.no

1877-0509 © 2012 Published by Elsevier B.V.
doi:10.1016/j.procs.2012.01.015

we today face up to climate change as a major environmental threat, the way forward becomes less certain.

According to IEA Outlook, there are four key drivers which will shape the future of energy, determining what we might call the "solution envelope" for the next 50 years [1]. They are the *growth in demand* for energy, the challenge of energy *supply*, concerns about energy *security* and *environmental constraints*, particularly the challenge of climate change. However, and despite that most of the literature and energy debate rhetoric agreed on those challenges (IEA, EIA IPCC, PB, Shell), we see different views and in some cases conflicting measures in addressing those challenges. The facts and data collected and their interpretation that work as a foundation for decision makers are full of uncertainties and based on many assumptions Uncertainties and assumptions that are not always communicated clearly. One of the implicit mechanisms might be that the political system gets more maneuvering space so it can pick up issues that fit into the political agenda. Oreskes and Conway [2] explain how a group of high-level scientists, with extensive political connections, ran effective campaigns to mislead the public and deny well-established scientific knowledge.

We propose to apply systems engineering methods and techniques on this problem. Systems engineering methods and techniques facilitate the development of complex systems from understanding the problem and its context up to analyzing and implementing technological solutions. Systems engineering is used to remove ambiguity and uncertainty in the problem statement, caused by the multitude of stakeholders and their concerns and by the complexity of the system context with its unknowns. Systems engineering tries to come close to the ideal of a holistic understanding, the big picture, and at the same time be specific and concrete by quantified modeling and analysis. Reaching this holistic "big picture" of the problem will help in identifying the conflicting interests among stake holders, in resolving those diversities and eventually focus all the efforts to come up with ultimate solutions.

We believe that clearer and better defined objectives that are agreed upon by all the stakeholders involved, will improve the transition process to a more sustainable energy future. The current fuzziness might disturb and delay the transition as well as waste resources in searching for ineffective solutions for a not fully defined problem. We will focus in this paper on the very early phases: problem understanding and exploration in addition to needs articulation.

2. Potential systems engineering contribution

The system approach as stated by Ramo [3] is "a technique for the application of a scientific approach to complex problem". It focuses on formulating an overview of the problem and to see the "big picture". In dealing with complexity and largeness of scale of the energy problem the authors believe that a system approach can help gaining greater insight into the energy problem and to move stakeholders closer toward more shared understanding. Adding to the complexity of addressing the energy problem is the fact that the problem depends on various factors rooted in different domains, technical, economical, political, informational and organizational. Moreover concerns of the applicability of those solutions locally as well as globally have to be addressed.

System approach can be utilized in addressing such complex problem because of the ability of this approach to take into account larger and larger numbers of interactions, instead of isolating smaller and smaller factors affecting the problem domain and analyzing them separately. Those factors and their interactions have then to be presented to the debate as simply and clearly as possible without disturbances and noise. Problem modeling techniques and analysis can be used to increase understanding, synchronize views and support decision making processes.

Examples of the application of systems engineering in this field are Haskins [4] and Fet [5]. Haskins has applied a systems engineering framework called IFACE to help residents of an industrial park establish a vision for their further sustainable development. Fet has conducted a project to map and evaluate the environmental performance of 10 industrial companies and the local community by using systems engineering methodology.

3. Case and problem statement

The global energy field is very large and complex. The interests of the many stakeholders are large too and often conflicting. Policy making in energy is done by politicians operating in a political force field with billions of civilians and many powerful energy industries. Experts and scientists play a supporting role and are often part of institutions. Oreskes and Conway [2] show in their book that policy making in this force field is difficult and can easily be manipulated. We experienced when collecting data to better understand the energy field that a lot of data and statements are fuzzy and seemingly inconsistent. We believe that a systems engineering approach, based on facts, analysis, and clear communication will result in better and more robust policies. The next subsections will elaborate a single example of clear, but seemingly inconsistent facts.

3.1. Example of problems in current energy debate

We made a quick exploration of literature in the energy field from many different sources. The initial collection of circa 100 graphs and diagrams was compressed into a 20 page report. Many diagrams do not correlate immediately. As an example we will look at the data for GDP growth in relation to energy. The executive director BP [7] shows a graph from UN and DOE EIA with historic data from 1980 to 2002 reproduced in Figure 1a. This historic data shows that the energy consumption per person is roughly proportional with the GDP per person. In fact, the graph shows a band between 5 and 10 MegaJoule per dollar; USA inhabitants are close to 10MJ/$, Irish people are closer to 5 MJ/$.

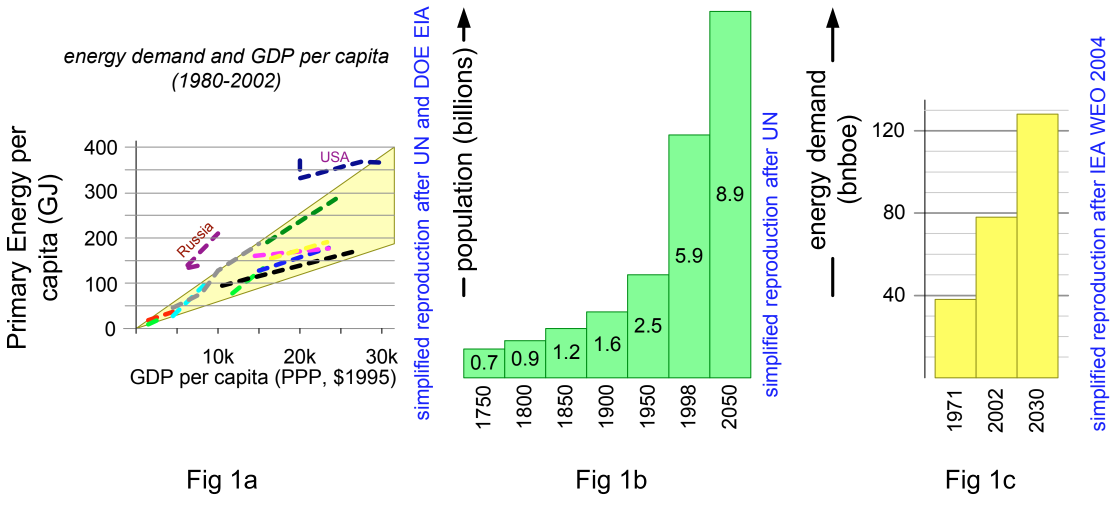

Figure 1. 1a Energy demand and GDP per capita, 1b population increase, 1c increase of energy demand [simplified reproduction after 1]

Many upcoming economies like Malaysia, Brazil, India and China show a steady increase in the use of energy as an increase in economic prosperity is proportional with the increase in energy use. In this figure roughly 1 billion people have already a high standard of living and an associated high energy use. About 2.5 billion people in the upcoming economies probably will quadruple their energy use, and another 3.5 billion people are not yet on this chart.

Figure 1c shows the projected growth in energy demand up to 2030. In numbers the energy demand in 2030 is expected to be 50 % higher than it is today.

The growth of the energy demand as shown in Figure 1c is presumably based on a complicated model that extrapolates current energy use, merges in an increase in global GDP, and at the same time merges all kinds of assumptions about feasibility and economic constraints. We have compared this increased energy demand with a simple GDP extrapolation using the CIA fact book [6] and with a time independent energy need. The simplistic extrapolation using today's GDP growth rate results in a GDP growth of more than a factor 3 in 20 years. Such GDP growth would create a much larger energy demand growth than Figure 1b shows (a factor of about 1.7 in 30 years).

We can also make an estimate of the energy need, by assuming that the entire global population strives for a GDP level per capita of Western countries and an associated energy use of about 150 GJ per year per person. For today's population of nearly 7 billion people that would require nearly four times the amount of energy consumption of today (assuming no further energy growth in the rich countries). We also found some data on the population growth, see Figure 1c. This prediction indicates a global population in 2050 of nearly 9 billion people. Again we did a quick comparison with a simplistic extrapolation based on the CIA fact book. The simplistic extrapolation of the population growth shows a much faster increase in the population, where 8.7 billion people are expected in 20 years.

The population growth adds another 25% energy use in 20 to 40 years time in the need estimation. Between 2030 and 2050 the need for energy would then be 5 times the current energy use (assuming no more energy will be used in the rich countries.

This quick and simplistic comparison shows that the predictions that are used in international literature have built in many mechanisms that result in a lower energy demand than naive extrapolation would give. Examples of such mechanisms are increased energy efficiency resulting in less energy per GDP, economic mechanisms (higher energy prices reducing use or GDP growth), and limitation mechanisms on oil, gas and coal production. The models might be well founded on arguments, but their complexity opens the door for doubt and lowers their credibility.

3.2. *Problem statement*

The energy problem is a complex problem that has impacts across broad geographies and over long time frames – problems with multiple, diverse stakeholders – problems that impact our economy, our health and well-being, our way of living, and our environment. With this variety of stakeholders –all with different perspectives, different goals, different constituencies, different measures of success – it is a challenge in itself for all involved to come to a shared understanding and agreement about how to work together to achieve the ultimate goal of sustainable energy future. According to R. Scott Spann [7], in the early phase of discussing a complex problem stakeholders need both the clarity and good communication to create the shared understanding and agreement concerning four necessary outcomes 1) the state of reality we seek to change 2) what's causing that reality, 3) where to intervene in that reality and 4) the structural then behavioral changes required to actually change that reality.

Today's energy debates and policies show that we are far away from such agreement and shared understanding. There are many mainstream reports and studies, such as [8] that are mostly seen as the basis for policy making. However, there is also a lot of critics on the main stream, e.g. [9], [10] and [11]. Worse is that the current state of understanding leaves a lot of room for manipulation [2]. The actual situation is that changes in energy production and use are slow; a symptom that there is a lack of understanding of current forecasts and the need for sustainability changes. The interpretation of the facts and data collected, which works as a foundation for decision makers, are full of uncertainties and based on many assumptions. A research question is how to communicate uncertainties and assumptions clearly, and what facts, in which form and how those facts can be communicated effectively.

The authors believe, in seeking clarity and simplicity, a scientific foundation of the variables involved together with a system approach to the problem is needed.

The challenge of moving to sustainable energy systems is complicated by several additional factors. First is the fact that different policy objectives can be in tension (or even at odds), especially if approached in isolation. For example, efforts to improve energy security in the US by using liquefied coal will lead to a massive expansion of coal use without concurrent carbon sequestration. Adopting such a solution could significantly exacerbate climate risks. Achieving an energy sustainable future almost certainly requires a holistic approach in which energy demand, energy supply, environmental limits, and energy security are addressed—even if they cannot always be resolved at the same time

3.3. Example of SE approach

The energy problems have been classified as: the *growth in dema*nd for energy, the challenge of energy *supply*, concerns about energy *security* and *environmental constraints*, particularly the challenge of *climate change*. The systems engineering approach is to sharpen the problem further by transforming it into need statements. The most high-level need statement is that we need sufficient energy to support the entire world population now and in the future with a life style as is common now in the rich countries. This energy supply must be robust and secure everywhere needed. No adverse effects of energy use are acceptable, such as pollution and CO_2 production.

The next step is to sharpen the need by quantification. A better understanding of the need is required. Systems Engineering uses modeling and analysis techniques to understand, communicate, debate, and facilitate decisions about complex problems and potential solutions. In the example we have shown that different models can be made to explore the actual need for energy, such as extrapolation of GDP, extrapolation of population growth, or more complicated models from IEA with mutual influences of production, demand, and economics.

In recent years many scientists have been calling to more simple and accessible approaches to the energy problem. Part of the point is that stakeholders don’t always need detail studies to reach to a useful understanding of the problem.

This approach is trying as much as possible to use quantitative analysis and modeling, with the aim of reaching to a fresh perspective on the energy problem. Explorations of this type can be used to bring clarity to a complex issue and using this clarity to evaluate the potential of proposed energy solutions. This relatively new approach is taking physics and engineering perspectives, in addition to politics or business. Bloggers like Tom Murphy and Dave Cohen are adopters to this new approach. There is the power of being able to assess the broad -brush aspects of the problem by things we already know, and putting relevant numbers together, Murphy explains. On the other hand, Dr David Mackay in his book [11] - sustainable energy without the hot air- endorses “Numbers not adjectives”. MacKay uses data, logic, and simple math to arrive at important conclusions that he further uses in assessing some of the proposed solutions. One of the book's other strengths - and what sets it apart from other mainstream literature about energy - is that it is almost free of politics and economics. The physics perspective brings insights that need embedding to become part of the political and economic decision making. Systems engineering as discipline operates in both worlds.

4. Conclusion

The world is facing major challenges in providing energy services to meet the future needs of the world and in particular the growing needs of the developing countries. These challenges are exacerbated by the need to provide energy services that take into account economic growth, security of supply and environmental sustainability. In this context, many questions can be asked what are the real needs and goals of humanity in terms of energy, prosperity, economical growth and what drives those needs? What level of prosperity humanity can achieve and afford without reaching a point where it is too late to turn. How much fossil fuel can we use in what time frame? Those questions and many others need to be answered explicitly including the assumptions that accompany the decision making process. Many answers might be valid and each must be treated with due respect. However, systems engineering practice wants the arguments to be explicitly on the table; preferably quantified. In this paper we are arguing that better understanding of the need is required. And to do so we are suggesting applying systems engineering's modeling and analysis techniques to understand, communicate, debate, and facilitate decisions concerning energy problem and in assessing potential solutions.

5. Future Research

This paper is written within the framework of a PhD research project. The central question in this project is: "Can we use system engineering methods and techniques to create and enhance a common understanding of the energy problem so the involved parties can judge every partial solution by placing it into the right domain of the energy problem?" Further work will focus on elaborating the energy problem statement using simple modeling to sharpen the needs and objectives, thereafter continuing the SE process by exploring candidate solutions. These models will cover a range: hard models to understand technical constraints and opportunities, economical models to assess economic feasibilities and hurdles, and soft models to understand social and political forces. Main key drivers of the modeling are clarity in communication, providing focus for energy researchers, and the facilitation of decision making for policy makers.

6. References

[1] Koonin,Steven E. Energy trends and technologies for the coming decades. *www.me.gatech.edu/docs/distinguished_lecture_07_slides.ppt* retrieved August 29, 2011

[2] Oreskes, Naomi. Conway, Erik M., 2010, Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming. Bloomsbury press. New yourk.USA

[3] Brill, James H . System ebgineering a retrospective View. John Wiley & Sons,Inc.Syst Eng 1 :258-266,1998

[4] Haskins, Cecilia. Systems engineering analyzed, synthesized, and applied to sustainable industrial park development. Doctoral thesis. 2008 Norwegian University of Science and Technology.

[5] Fet , Annik Magerholm, NTNU. Moritz, Anette, technological Institute , Arbaciauskas Valdas, APINI"Fram work for sustainability reporting in the Klaipeda region , Lituania", 2004 (NTNU /Global & Local report)

[6] CIA factbook https://www.cia.gov/library/publications/the-world-factbook/rankorder/2001rank.html retrieved July 27, 2011

[7] Scott Spann, R. http://www.innatestrategies.com/docs/REAMPFinal.pdf retrieved July 27, 2011

[8] International Energy Agancy (IEA). World energy outlook 2006. http://www.iea.org/weo/2006.asp retrieved July 15, 2011

[9] Murphy, Tom. Do the Math: using physics and estimation to assess energy, growth, options. Blog: http*://physics.ucsd.edu/do-the-math/* retrieved August 25, 2011

[10] Cohen, Dave .Economical growth and climate change, no way out. http://www.energybulletin.net/node/51413 retrieved August 26, 2011

[11] David MacKay. Sustainability without hot air, http://www.withouthotair.com/pdf retrieved August 10, 2011

[12] Pyster, A., D. Olwell, A. Squires, N. Hutchison, and S. Enck, eds. 2010. A Guide to the Systems Engineering Body of Knowledge (SEBoK). Version 0.25. Released for limited review. Hoboken, NJ (US): Stevens Institute of Technology.

[13] Squires, A., A. Pyster, D. Olwell, S. Few, and D. Gelosh. 2009. "Announcing BKCASE: Body of Knowledge and Curriculum to Advance Systems Engineering." INSIGHT 12 (4): 69–70.

[14] Sauser Brian, Boardman John. System thinking, Coping with 21st Century Problems .Taylor & Francis Group .USA 2008